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(54) Vehicle Location System

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VEHICLE LOCATING SYSTEM

ABSTRACT OF THE DISCLOSURE

5 A vehicle locating system (VLS) comprises a large number, for example, several million, vehicle-mounted transmitters and several benchmark transmitters; first, second and third signal relay stations and a central processing station at which the transmitter locations are determined, the central station being connected by conventional links to subscriber stations. One hundred
10 microsecond-long RF signals are transmitted by each transmitter in a non-synchronized, mutually random manner. Each signal comprises a 20 microsecond synchronization symbol followed by six, four bit transmitter identification symbols, each of ten microseconds length.
15 Following the identification symbols are 10 microsecond message and processing symbols. The control station includes correlation means for correlating the synchronization symbols on each relayed signal against stored data to identify the beginnings of the signals.
20 Identification symbols of each signal are then decoded by correlation means to establish transmitter identification, a combination of 16^6 possible identifications being provided. Signals arriving in the central station are time-tagged upon arrival and the time differences of arrival (TDOA) are used to compute transmitter
25 location. Benchmark transmitter computed locations are used to calibrate the VLS. Means may be provided on the vehicle transmitters to enable the rate of transmissions to be varied, to thereby enable encoding preselected messages relating, for example, to vehicle motion,
30 vehicle crashes and vehicle intrusion/theft, responsive to associated sensors. Alternatively, or in addition, specific, prestored messages may be encoded into the transmitted signals manually or automatically in
35 response to sensor input.

VEHICLE LOCATING SYSTEM

BACKGROUND OF THE INVENTION

1 Field of the Invention: The present invention relates
generally to apparatus and methods for remotely
determining the location of such movable objects as
automobiles, trucks, railway cars, ships and boats,
5 (generically referred to as vehicles), and more
particularly to apparatus and methods for determining
the locations of such objects at a centralized control
station by the processing of radio frequency
transmissions from transmitters mounted on the objects.

10 Background Discussion: Information concerning the
location of surface vehicles, ships, airplanes and the
like is important for many reasons, including business,
safety and security reasons. As is well known, the
15 apparatus and methods used to determine the location of
such objects have varied greatly over the centuries and
have been greatly improved in accuracy and
sophistication during the past several decades.

20 Historically, for example, early ocean navigators
relied upon often extensive knowledge of ocean currents,
prevailing wind directions and the positions of stars in
the sky to determine their locations when out of sight
of familiar landmarks, and to thereby chart their paths
to intended destinations. Subsequent navigators had
available chronographs, compasses, astrolabes and

1 sextants by which to determine their approximate
positions. Still more recently, ocean and air
navigation has benefited from various types of radio
location apparatus, including LORAN and variations
5 thereof. Modern ships and aircraft may presently rely
upon radar, inertial navigation apparatus and satellite
navigation systems by which positional information can
usually be determined with great precision.

Land navigation has generally been easier than ocean
10 and air navigation, at least after traveled regions of
the earth were accurately mapped. Known landmarks could
always be relied up in determining positional locations
on land; in unmapped or unfamiliar regions, ocean
navigation apparatus and methods have been used.

15 Presently, at least under normal circumstances, the
knowledge of one's location in most habited regions of
the world is relatively easy for a vehicle operator to
determine from available maps or by inquiry from local
inhabitants. It is, however, generally a more difficult
20 and costly problem for control centers remote from the
vehicles to determine, at all practical times, the
location of a number of vehicles which may be under
direct or indirect supervision by the control center.
Even assuming that the vehicle operators themselves know
25 their vehicle locations, difficulties exist in
continually providing such location information to a
control center which may be responsible for supervising
a great many vehicles.

Telephone communication of vehicle position on a
30 periodic basis is, of course, possible and may, for
example, be used by sales personnel who may otherwise
routinely telephone their headquarters to report their
activities and obtain messages. In many instances,
however, frequent telephone communication is impractical
35 and may, in any event, be very costly. Verbal

1 communication from vehicle operators to a control
center, by use of on-board, short wave radio
transmitters, is frequently used to provide local area
positions of trucks, taxi cabs, police cars, ambulances
5 and fire trucks to central dispatchers. However, such
radio communications are usually impractical for long
ranges, are relatively costly on a per-vehicle basis and
require operator intervention.

Various vehicle location systems of a more
10 sophisticated nature have been disclosed, for example,
in U.S. Patent Nos. 4,215,345 to MacDoran and 4,359,733
to O'Neill. The O'Neill patent discloses a
satellite-based vehicle position determining system
which utilizes coded radio signals from transponders
15 carried aboard land vehicles and aircraft. Relay
stations on artificial satellites are used to relay the
radio signals from the vehicles and/or aircraft to a
remote control station which uses time of signal arrival
to determine vehicle or aircraft position. The radio
20 signals from the vehicles or aircraft are, however,
provided only in response to an interrogation signal
sent to transponders on the vehicle and aircraft. Thus,
in such systems, two-way communication with the vehicles
and aircraft is required and each vehicle and aircraft
25 thus requires both a transmitter and a receiver. When
such equipment is already available for other purposes
on the vehicles and aircraft, low vehicle location
equipment costs may result. However, in most instances
involving land vehicles, appropriate radio communication
30 receivers and transmitters are not already provided and
the cost of adding such equipment must accordingly be
borne by the vehicle location system as part of the
overall system cost.

The MacDoran patent discloses a vehicle locating
35 system based upon the detection by several stations of

1 radio signals transmitted from vehicles. Precise,
time-formatted radio signal receptions from each station
are retransmitted, after time-tagging, to a central
station where the signals are cross correlated with all
5 other signals to determine the time-differences-of-
arrival from the vehicle for all possible station
pairs. The central station processes the time
differences of arrival data to locate the vehicle's
position at the intersection of derived hyperboloids.
10 As disclosed by MacDoran, noise characteristics of each
transmitted pulse are utilized to determine the time
differences of arrival from all pairs of receiving
stations, the presence or absence of cross correlation
signals being used for decoding the vehicle identity.
15 All receiving stations must, however, be synchronized by
a calibration beacon and the system is incapable of
handling overlapping signals, the latter factor limiting
the system, as stated in the disclosure, to no more than
about 100 vehicles.
20 There exists, therefore, a need for a comparatively
low cost vehicle locating system that has the capability
for handling many thousands or millions of vehicles, as
well as for a vehicle locating system that does not
require special synchronization and does not require
25 costly two-way communication apparatus.

SUMMARY OF THE INVENTION

A vehicle locating system, according to the present
invention, provides for remotely determining the
30 locations of a comparatively large number of vehicles
operating within a specific geographical region.
Comprising the vehicle locating system are a number of
similar, automated radio frequency transmitters adapted
for mounting on vehicles and first, second and third
35 (and possibly a fourth) elevated relay stations for

1 receiving transmitted signals from the vehicle-mounted
transmitters and for relaying such signals to a central
processing station at which the relayed signals are
processed to obtain vehicle location information, for
5 example, to be provided to system subscribers.

Each of the transmitters is configured for
transmitting radio frequency signals that are similar
for all transmitters except that each transmitter has
means for encoding into its transmitted signals a unique
10 transmitter identification code. Further, each
transmitter includes means for causing its signals to be
transmitted at a predetermined repetition rate.
Importantly, each transmitter operates independently of
all other transmitters, the transmitters thus operating
15 in a mutually random manner.

The central processing station of the invention is
configured for separately receiving the relayed signals
from the first, second and third relay station, which
are spaced apart from one another at known locations
20 relative to the geographical region covered by the
vehicle locating system. Comprising the central
processing station are means for separating the
received, relayed signals from one another, especially
when the incoming signals are overlapping; means for
25 encoding on the received signals the time of arrival at
the processing station and means for determining from
time differences of arrival (TDOA) of the signals the
location of the associated transmitters, and thus the
location of the vehicles on which the transmitters are
30 mounted.

To enable separation of the relayed signals, each
transmitter includes means for encoding a preestablished
synchronization code into each transmitted signal, the
synchronization code being the same for all transmitters.
35 Preferably, this synchronization code is encoded into a

1 synchronization symbol at the beginning of each signal
transmitted. This synchronization symbol may, for
example, be no more than about twenty microseconds
5 long. Following the synchronization symbol are
transmitter identification symbols; preferably six
identification symbols are provided and preferably each
such symbol has four data bits which enable sixteen
different numbers per identification bit. With such a
data provision, 16^6 (16,772,216) number combinations
10 are possible so that an equal number of transmitters can
be individually identified.

 Within the central processing station, the means
for separating the relayed signals from one another
include means for correlating the synchronization data
15 encoded into the synchronization symbol with a
corresponding stored code in a manner enabling the
beginning of individual signals to be identified even in
the presence of overlapping signals. Data correlation
means are provided for determining from the signal
20 identification symbols the transmitter identification,
and hence the identification of the vehicle to which the
identified transmitter is mounted. To decode the
identification symbols, the data correlating means
correlate each of the data bits with stored possible
25 codes. Thus, for example, each information symbol which
comprises four binary bits is compared, as it is
received, with the sixteen possible combinations to
determine which combination of bits is contained in the
symbol. Preferably, each entire signal is no longer
30 than about one hundred microseconds. Also, preferably,
the transmitters format their signals in a spread
spectrum format so as to enhance the ability of the
central processing station to separate the signals and
to decode the signals after separation.

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1 In an embodiment of the invention, at least some of
the transmitters include means for enabling the
repetition rate of the signals to be varied to enable
communication of messages from the transmitters to the
5 central processing station by merely changing the signal
repetition rate. In such case, motion sensing means may
be associated with some of the transmitters. Responsive
to the motion sensing means, the means for varying the
signal repetition rate may cause the signals to be
10 repeated at a first rate when the motion sensing means
indicates that the transmitter is at rest and at a
second repetition rate when the motion sensing means
indicates that the transmitter is moving. The signal
repetition rate associated with the transmitter being at
15 rest may be substantially less than the repetition rate
when the transmitter is moving so that signal traffic
may be reduced over that which would otherwise occur if
all the transmitters transmitted at the moving
transmitter rate.

20 Vehicle anti-theft means may be included for some
vehicles whose transmitters have signal repetition rate
varying capability. Responsive to electric signals from
the vehicle anti-theft means, the transmitter may be
caused to transmit signals at a predetermined repetition
25 rate associated with a vehicle tampering situation so
that such information can be provided by the central
processing station to subscribers. In addition, or
alternatively, according to an embodiment of the
invention, crash sensing means may be provided on
30 vehicles equipped with variable repetition rate
transmitters. Responsive to an output from the crash
sensing means that indicates the probability of a
vehicle crash, the signal transmission rate is shifted
to a predetermined rate associated with a crash
35 situation. Still further, some transmitters may include

means for selectively encoding preestablished message codes into the transmitted signals for decoding at the central processing station.

It is still further preferred that the vehicle location system includes at least one benchmark transmitter mounted at a known, fixed location relative to the geographical region covered by the system. The benchmark transmitter is configured to transmit radio frequency signals similar to those transmitted by the vehicle-mounted transmitters, signals from the benchmark transmitter being processed in the same manner as those of the vehicle-mounted transmitters to determine the location of the benchmark transmitter. Differences between the actual, known location of the benchmark transmitter and the computed location thereof can be used to calibrate the system, including the locations of the relay stations.

Because a very large number of vehicles can be accommodated by the vehicle locating system of the present invention, the per-vehicle procurement and operating costs of the system can be very low and, therefore, attractive to system subscribers.

Other aspects of this invention are as follows:

A vehicle locating system for remotely determining the locations of a comparatively large number of vehicles operating within a specific geographical region, the vehicle locating system comprising:

- a. a number of similar, automated radio frequency transmitters adapted for mounting on vehicles, each of said transmitters being configured for transmitting radio frequency signals that are similar except that each transmitter has means for encoding onto the signal transmitted thereby a unique transmitter identification

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5 code, each of the transmitters having means
for causing the transmitted signals to be
repeated at predetermined intervals, each of
the transmitters operating independently of
one another and hence in a random manner
relative to one another;

10 each said transmitter including means for
encoding a synchronization code into each
transmitted signal, the synchronization code
being the same for each said transmitter;

b. first, second and third elevated radio signal
15 relay stations for receiving the radio
frequency signals from said transmitters and
for relaying said received signals, the relay
stations being spaced apart from one another
in known locations relative to said
geographical region covered by the vehicle
locating system;

c. a central processing station having means for
20 separately receiving the relayed radio
frequency signals from each of the relay
stations, means for encoding onto the received
signals the time of arrival at said processing
station and means for determining from time
25 differences of arrival (TDOA) of the signals
from the relay stations a location of each
transmitter that is transmitting signals;

the central processing means for
30 separating the relayed signals from one
another including means for correlating the
signal synchronization code with a
corresponding stored signal synchronization
code in a manner enabling individual signals
to be identified even in the presence of
35 overlapping signals.

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A vehicle locating system for remotely determining the locations of a comparatively large number of vehicles operating within a specific geographical region, the vehicle locating system comprising:

- 5
- a. a number of similar, automated radio frequency transmitters adapted for mounting on vehicles, each of said transmitters being configured for transmitting radio frequency signals that are
- 10 similar except that each transmitter has means for encoding onto the signal transmitted thereby a unique transmitter identification code, each of the transmitters having means for causing the transmitted signals to be
- 15 repeated at predetermined intervals, each of the transmitters operating independently of one another and hence in a random manner relative to one another;
- each of the transmitted signals being
- 20 formatted having a synchronization symbol at the beginning of each signal, followed by a plurality of transmitter identification symbols;
- b. first, second and third elevated radio signal
- 25 relay stations for receiving the radio frequency signals from said transmitters and for relaying said received signals, the relay stations being spaced apart from one another in known locations relative to said
- 30 geographical region covered by the vehicle locating system;
- c. a central processing station having means for separately receiving the relayed radio
- 35 frequency signals from each of the relay stations, means for encoding onto the received signals the time of arrival at said processing station and means for determining from time

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differences of arrival (TDOA) of the signals from the relay stations a location of each transmitter that is transmitting signals;

5 the central processing means for separating the relayed signals from one another including synchronization correlation means for detecting the synchronization symbol at the beginning of each received signal and data correlating means for determining from
10 the identification symbols following the synchronization symbol the transmitter identification associated with each received signal.

15 A vehicle locating system for remotely determining the locations of a comparatively large number of vehicles operating within a specific geographical region, the vehicle locating system comprising:

20 a. a number of similar, automated radio frequency transmitters adapted for mounting on vehicles, each of the transmitters including means for formatting signals to be transmitted by the transmitters, said signal formatting means
25 formatting the signals with a synchronization symbol followed by a plurality of transmitter identification symbols, the synchronization symbol containing the same data for all the transmitters and the transmitter
30 identification symbols containing data uniquely identifying the associated transmitter, each of the transmitters further including means for causing the signals
35 transmitted by the transmitters to be repeated at a predetermined repetition rate, each of the transmitters operating independently of



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one another and hence in a mutually random manner;

b. first, second and third elevated radio signal relay stations for receiving the signals transmitted by the transmitters and for relaying said received signals, the relay stations being spaced apart from one another in known locations relative to the geographical region covered by the vehicle locating system; and

c. a central processing station having means for separately receiving the relayed radio frequency signals from each of the relay stations, means for separating the relayed signals from one another, means for encoding onto the received signals the time of arrival at the processing station and means for determining from time differences of arrival of the signals at the processing station a location of each transmitter that is transmitting signals, said means for separating the relayed signals from one another including synchronization correlation means for determining from the synchronization symbol the beginning of individual ones of the relayed signals and data correlating means for determining from the identification symbols the transmitter identification code associated with each received signal.

30 A vehicle locating system for remotely determining the locations of a comparatively large number of vehicles operating within a specific geographical region, the vehicle locating system comprising:

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- 5 a. a number of similar, automated radio frequency transmitters adapted for mounting on vehicles, each of said transmitters being configured for transmitting radio frequency signals that are similar for all said transmitters except that each transmitter has means for encoding onto the signal transmitted thereby a unique transmitter identification code, and each of
- 10 said transmitters having means for encoding a synchronization code into each transmitted signal, the synchronization code being the same for each said transmitter, each of the transmitters further including means for causing the signals to be repeated at a
- 15 predetermined repetition rate, each of the transmitters operating independently of one another and hence in a mutually random manner, at least some of the transmitters having means enabling the signal repetition rate to be
- 20 varied so as to enable messages to be sent by the at least some of the transmitters by varying the signal repetition rate;
- 25 b. first, second and third elevated radio signal relay stations for receiving the radio frequency signals from said transmitters and for relaying said received signals, the relay stations being spaced apart from one another in known locations relative to said geographical region covered by the vehicle locating system; and
- 30 c. a central processing station having means for separately receiving the relayed radio frequency signals from each of the relay stations, means for separating the relayed
- 35 signals from one another, means for encoding into the received signals the time of arrival at said processing station, means for
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determining from differences in time arrival of the signals from the relay stations a location of each transmitter that is transmitting signals, and means for correlating the signal synchronization code with a corresponding stored signal synchronization code in a manner enabling individual signals to be identified even in the presence of overlapping signals.

10 A vehicle locating system for remotely determining the locations of a comparatively large number of vehicles operating within a specific geographical region, the vehicle locating system comprising:

- 15 a. a number of similar, automated radio frequency transmitters adapted for mounting on vehicles, each of said transmitters being configured for transmitting radio frequency signals that are similar for all said transmitters except that
- 20 each transmitter has means for encoding onto the signal transmitted thereby a unique transmitter identification code, each of the transmitters further including means for causing the signals to be repeated at a
- 25 predetermined repetition rate, each of the transmitters operating independently of one another and hence in a mutually random manner, at least some of the transmitters having means enabling the signal repetition rate to be
- 30 varied so as to enable messages to be sent by the at least some of the transmitters by varying the signal repetition rate;
- 35 b. first, second and third elevated radio signal relay stations for receiving the radio frequency signals from said transmitters and for relaying said received signals, the relay




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stations being spaced apart from one another in known locations relative to said geographical region covered by the vehicle locating system;

- 5 c. a central processing station having means for separately receiving the relayed radio frequency signals from each of the relay stations, means for separating the relayed signals from one another, means for encoding
10 into the receive signals the time of arrival at said processing station and means for determining from differences in time arrival of the signals from the relay stations a location of each transmitter that is
15 transmitting signals; and
- d. motion sensing means associated with said at least some of the transmitters and wherein the means for enabling the signal repetition rate to be varied causes the transmitter to
20 transmit signals at a first repetition rate when the motion sensing means senses that the transmitter is at rest and at a second repetition rate when the motion sensing means senses that the transmitter is in motion, the
25 first signal repetition rate being substantially less than the second signal transmission rate so that fewer signals are transmitted by those transmitter that are at rest than by those transmitters that are in
30 motion, signal traffic being thereby reduced over that which would otherwise occur if all transmitters transmitted signals at the second rate.

 A vehicle locating system for remotely
35 determining the locations of a comparatively large number of vehicles operating within a specific



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geographical region, the vehicle locating system comprising:

- 5 a. a number of similar, automated radio frequency transmitters adapted for mounting on vehicles, each of said transmitters being configured for transmitting radio frequency signals that are similar for all said transmitters except that each transmitter has means for encoding onto the signal transmitted thereby a unique transmitter identification code, each of the transmitters further including means for causing the signals to be repeated at a predetermined repetition rate, each of the transmitters operating independently of one another and hence in a mutually random manner, at least some of the transmitters having means enabling the signal repetition rate to be varied so as to enable messages to be sent by the at least some of the transmitters by varying the signal repetition rate;
- 10 15 20
- 25 b. first, second and third elevated radio signal relay stations for receiving the radio frequency signals from said transmitters and for relaying said received signals, the relay stations being spaced apart from one another in known locations relative to said geographical region covered by the vehicle locating system;
- 30 35 c. a central processing station having means for separately receiving the relayed radio frequency signals from each of the relay stations, means for separating the relayed signals from one another, means for encoding into the receive signals the time of arrival at said processing station and means for determining from differences in time arrival of the signals from the relay stations a

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location of each transmitter that is transmitting signals; and

- d. vehicle anti-theft means adapted for installation on vehicles to which said at least some of the transmitters are mounted, said anti-theft means providing an electric signal in response to tampering of the vehicle in which the anti-theft means are installed, and wherein said means for enabling the repetition rate of the signal to be varied is responsive to the electric signal from the anti-theft means indicating a vehicle tampering condition for causing the signal repetition rate to be increased from the normal transmitting rate to a preselected transmission rate associated with a vehicle tampering situation.

A vehicle locating system for remotely determining the locations of a comparatively large number of vehicles operating within a specific geographical region, the vehicle locating system comprising:

- a. a number of similar, automated radio frequency transmitters adapted for mounting on vehicles, each of said transmitters being configured for transmitting radio frequency signals that are similar for all said transmitters except that each transmitter has means for encoding onto the signal transmitted thereby a unique transmitter identification code, each of the transmitters further including means for causing the signals to be repeated at a predetermined repetition rate, each of the transmitters operating independently of one another and hence in a mutually random manner, at least some of the transmitters having means enabling the signal repetition rate to be

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varied so as to enable messages to be sent by the at least some of the transmitters by varying the signal repetition rate;

- 5 b. first, second and third elevated radio signal relay stations for receiving the radio frequency signals from said transmitters and for relaying said received signals, the relay stations being spaced apart from one another in known locations relative to said
- 10 geographical region covered by the vehicle locating system;
- c. a central processing station having means for separately receiving the relayed radio frequency signals from each of the relay
- 15 stations, means for separating the relayed signals from one another, means for encoding into the receive signals the time of arrival at said processing station and means for determining from differences in time arrival
- 20 of the signals from the relay stations a location of each transmitter that is transmitting signals; and
- d. vehicle crash sensing means adapted for installing on vehicles to which said at least
- 25 some of the transmitters are mounted and wherein the means for enabling the signal repetition rate to be varied is responsive to the vehicle crash sensing means indicating a vehicle crash condition for causing the
- 30 signal transmission rate to be increased from the normal transmitting rate to a preselected transmitting rate associated with a vehicle crash situation.

 A vehicle locating system for remotely

35 determining the locations of a comparatively large number of vehicles operating within a specific



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geographical region, the vehicle locating system comprising:

- 5 a. a number of similar, automated radio frequency transmitters adapted for mounting on vehicles, each of said transmitters being configured for transmitting radio frequency signals that are similar for all said transmitters except that each transmitter has means for encoding onto the signal transmitted thereby a unique transmitter identification code, each of the transmitters further including means for causing the signals to be repeated at a predetermined repetition rate, each of the transmitters operating independently on one another and hence in a mutually random manner, at least some of the transmitters having means enabling the signal repetition rate to be varied so as to enable messages to be sent by the at least some of the transmitters by varying the signal repetition rate;
- 10 b. first, second and third elevated radio signal relay stations for receiving the radio frequency signals from said transmitters and for relaying said received signals, the relay stations being spaced apart from one another in known locations relative to said geographical region covered by the vehicle locating system;
- 15 c. a central processing station having means for separately receiving the relayed radio frequency signals from each of the relay stations, means for separating the relayed signals from one another, means for encoding into the receive signals the time of arrival at said processing station and means for determining from differences in time arrival of the signals from the relay stations a
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location of each transmitter that is transmitting signals; and

- d. means associated with at least some of the transmitters for storing preselected message codes and means for enabling said message codes to be selectively encoded into signals transmitted by said at least some of the transmitters.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention can be better understood by a consideration of the drawings in which:

FIG. 1 is a pictorial drawing depicting a vehicle locating system (VLS) in accordance with the present invention, showing, by way of illustrative example, a nationwide VLS covering the Continental United States:

FIG. 2 is a functional block diagram of a representative radio frequency (RF) transmitter used in the VLS of FIG. 1 showing major parts of the transmitter;

FIG. 3 is a diagram of the RF signal transmitted by the transmitter of FIG. 2 showing the signal divided

1 into its various symbols and showing the manner in
which spread spectrum techniques are applied to represent
the synchronization symbol of the signal by a large
number of signal elements, called chips;

5 FIG. 4 is a diagram depicting the typical output of
a sequencer portion of the transmitter;

FIG. 5 is a perspective drawing of a short,
cylindrical package in which the transmitter of FIG. 2
can be mounted and by means of which the transmitter can
be mounted on a vehicle or other object;

10 FIG. 6 is a functional block diagram of the central
data processing station at which transmitter (vehicle)
location determinations are made;

FIG. 7 is a functional block diagram of a
representative signal correlator used in the central
data processing station;

15 FIG. 8 is a functional block diagram of a signal
synchronization correlator portion of the correlator of
FIG. 7; and

20 FIG. 9 is a flow diagram of the operation of the
central processing station.

DESCRIPTION OF THE PREFERRED EMBODIMENT

25 A vehicle locating system (VSL) 20, in accordance
with the present invention, is pictorially shown in FIG.
1. As depicted, and by way of illustrative example of
the invention, VLS 20 is operative over the entire
Continental United States and may, therefore, be
considered a nationwide vehicle locating system (NVSL).
30 However, VLS 20 is limited neither to the Continental
United States nor to any other specific region and may
be used to advantage in most geographical areas of the
world, subject to certain limitations that will become
apparent from the following description. Neither is VLS
35 20 limited to large, continental areas, but may be

1 advantageously used in such smaller areas as states,
counties and cities.

5 As more particularly described below, VLS 20 is
configured to provide vehicle location information at a
remote, off-vehicle location, and does not specifically
provide for vehicle location information to be made
available to the vehicles associated with the VLS.
Accordingly, a principal objective of the invention is
to provide, at a comparatively low cost, location
10 information regarding a large number of vehicles at a
centralized control center from which the vehicle
information can be communicated, by conventional,
preexisting means, to such system subscribers as
trucking, bus, vehicle rental and railroad companies or
15 to other companies or individuals having an interest in
being provided updated vehicle location information.

It is emphasized that the term "vehicle" as used
herein should be broadly construed to include not only
automobiles, trucks and buses, but also virtually any
20 type of movable object such as boats, ships, railroad
engines, rolling stock, construction equipment, portable
shelters and aircraft. Moreover, the present VLS is
also adaptable for use with and by individuals.

VLS 20, as described herein, importantly enables a
25 relatively low per-vehicle implementing and operating
cost by the use of small, low cost, standardized vehicle
transmitters which randomly, with respect to each other
(as opposed to synchronously), transmit radio frequency
(RF) signals which are similar for each transmitter
30 except for unique transmitter identification coding.

Illustrated in Fig. 1 as comprising VLS 20 is a
central processing station or center 22 at which vehicle
locations are computed from transmitted signal time
differences of arrival (TDOA). Further comprising VLS
35 20 are at least first, second and third elevated radio

1 signal relay stations 24, 26 and 28 which receive
vehicle transmitter RF signals and relay or
retransmit these signals to processing center 22 for
5 processing. Also comprising VLS 20 are a large number
of what may be termed "vehicle transmitters", only three
of which are shown in FIG. 1, being identified by the
reference numbers 30, 32 and 34. The number of vehicle
transmitters used in or accommodated by any specific VLS
10 depends upon such factors as the size of the
geographical region served by the VLS, the number of
subscribers to the VLS service and the purpose and scope
of the VLS involved. The number of vehicle transmitters
may thus vary widely between, for example, a few hundred
and several million. However, VLS 20 of the present
15 invention is especially useful for very large numbers of
vehicle transmitters because of its unique data handling
capability.

Further comprising VLS 20 are one or more
calibration or benchmark transmitters. Three such
20 benchmark transmitters are depicted in Fig. 1, being
identified by reference numbers 40, 42 and 44. These
benchmark transmitters 40, 42 and 44 are ground-mounted
in widely-spaced apart, fixed locations so as to cover
the region served by VLS 20. Preferably, but not
25 necessarily, benchmark transmitters 40, 42 and 44 are
constructed similarly to vehicle transmitters 30, 32 and
34 and in any event transmit similar RF signals. These
benchmark RF signals are relayed along with RF signals
from vehicle transmitters 30, 32, 34 (etc.) by relay
30 stations 24, 26 and 28 to processing station 22.
Because the locations of benchmark transmitters 40, 42
and 44 are precisely known, the benchmark RF signals can
be used to calibrate the system and to establish the
exact locations of relay stations 24, 26 and 28 to
35 enable compensation for any movement thereof from their

1 "fixed" locations. It will, of course, be understood
that knowledge of the precise locations of relaystations
24, 26 and 28 relative to control station 22 is
5 necessary to enable accurate determination of the
locations of the vehicle transmitters 30, 32, 34 (etc.)
relative to a preestablished grid system or map.

Vehicle transmitters 30, 32 and 34 are depicted, by
way of example in FIG. 1, as being mounted on respective
wheeled vehicles 30a, 32a and 34a. Also by way of
10 example, relay stations 24, 26 and 28 are depicted in
Fig. 1 as being mounted on respective artificial
satellites 46, 48 and 50, which are in geosynchronous
orbits above the region (for example, the Continental
United States) served by VLS 20. The mounting of relay
15 stations 24, 26 and 28 on geosynchronous satellites 46,
48 and 50 (assuming proper satellite selection and
positioning) advantageously enables each relay station
24, 26 and 28 to be in a line-of-sight relationship with
processing station 22, with benchmark transmitters 40,
20 42 and 44 and ordinarily with all of vehicle
transmitters 30, 32, 34 (etc.), thereby assuring good
reception by the relay stations of signals transmitted
by the benchmark and vehicle transmitters, and also
ensuring good reception of the relayed signals by
25 processing station 22.

However, for more localized VLS's all or some of
relay stations 24, 26 and 28 may be ground based, being,
for example, installed in high mountain locations, atop
tall buildings or on radio towers. Because relay
30 stations 24, 26 and 28 are merely RF signal repeaters
and perform no data processing, the stations are not
large and, in the case of satellite mounting, do not
require "dedicated" satellites, but can be carried

1 aboard commercial satellites used principally for other
purposes.

5 Also depicted in FIG. 1, but not comprising part of
VLS 20, are two representative subscriber stations 60 and
62 which are illustrated as being respectively
connected, for communication purposes, to processing
station 22 by preexisting telephone lines 64 and by a
microwave or radio link 66. Ordinarily, many such
subscriber stations would be connected by conventional
10 communication links to processing station 22.

Vehicle transmitters 30, 32, 34 (etc.) are
constructed as shown in FIG. 2, vehicle transmitter 30
being illustrated and described as representative of all
vehicle transmitters and also of benchmark transmitters
15 40, 42 and 44. Generally comprising transmitter 30 are
a reference oscillator or "clock" 70, a sequencer or
operation timer 72, memory means 74, a low pass filter
76, exciter means 78, a power amplifier 80, a pulse
forming network 82 and an antenna 84. In turn, shown
20 comprising exciter means 78 are an L-band oscillator 86,
a phase lock loop 88 and a summer 90. There may be
connected to sequencer 72 such auxiliary equipment as a
motion sensor 100, a crash sensor 102, vehicle anti-theft
means 104 and manual message selecting means 106.

25 Motion sensor 100 and crash sensor 102 preferably
comprise conventional accelerometers which may be set or
selected for different "g" levels of acceleration.
Motion sensor 100 is preferably set for a much lower "g"
level than crash sensor 102 so that a distinction can be
30 made between normal "g" levels associated with vehicle
movement and high "g" levels expected when a vehicle
crashes. Anti-theft means 104 is any commercially
available or custom vehicle anti-theft apparatus which
provides an electric signal in response to vehicle
35 intrusion, tampering or unauthorized movement. In turn,

1 message selecting means 106 may comprise a conventional
keyboard or switch (not shown) by means of which several
prestored message codes may be selected for encoding in
the RF transmission of associated vehicle transmitter 30.

5 Sequencer 72 controls the RF signal repetition rate
and the formatting of the RF signal. Memory means 74,
which preferably comprises first and second PROMs
(programmable read only memories) 110 and 112,
respectively, and a data buffer 114, contains signal
10 formatting information, including the transmitter
identification code (stored in first PROM 110) and
specific message codes (stored in second PROM 112).
Codes for a limited number of such messages as "need
assistance," "accident," and "out of service" may be
15 stored in PROM 112 and may be automatically selected by
signals from crash sensor 102, anti-theft means 104 or
manually by manual message selecting means 106.

Transmitter 30 is advantageously configured to
provide an RF message signal 120 of the format depicted
20 in Fig. 3. As so depicted, signal 120 may be 100
microseconds long and may include a 20 microsecond
synchronization symbol 122 followed by six (6) data
symbols 124, each of which may contain four (4) data
bits or information and may be 10 microseconds long.
25 Data symbols 124 are used to format the transmitter
identification code or number, there being the
possibility of 16^6 (16,777,216) possible vehicle
identifications, which can be provided by data symbols
124.

30 A four bit field symbol 126, also 10 microseconds
long, follows the data symbols 124 and 16 codes are
therefore available for message encoding. Some codes in
field symbol 126 may alternatively be used for signal
processing instructions. Following field symbol 126 may
35

1 be a 10 microsecond processing symbol used for time
tagging, as described below.

5 To enable processing a large number of transmitter
signals which may be only slightly separated in time,
signals 120 are preferably formatted by known
"spread spectrum" techniques. Such techniques, are, for
example, described in "Spread Spectrum Systems" by R.C.
10 Dixon, John Wiley and Sons, Publishers, 1976, and in the
present case preferably provide a "chip" rate of about
6.4 million chips per second. Synchronization symbol
122 is thus sub-divided into 128 chips which comprise a
pseudo-random pattern of binary ones and zeros. By
"pseudo-random" it is meant that the pattern of ones and
15 zeros is quasi-random but the pattern is known. Each
vehicle transmitter 30, 32, 34 (etc.) and each benchmark
transmitter 40, 42 and 44 is configured to provide the
same synchronization pattern of chips by which the
beginning of each signal can be identified. Vehicle
identification symbols 124 are similarly spread spectrum
20 formatted, each being formed of 64 chips which are
arranged in a specific pseudo-random manner of binary
ones and zeros. Symbols 126 and 128 are similarly
formatted.

In the preferred embodiment described herein,
25 signal 120 transmitted by vehicle transmitter 30 is
repeated at specific intervals (Fig. 4); however, field
symbol 126 may be differently formatted to incorporate
particular message codes, if provision is made for such
coding. Signals 120 may, for example, be repeated at
30 intervals of one minute so that the transmitter
(vehicle) location information provided to system
subscribers is always current.

Assuming, by way of example, a nominal repetition
rate of one signal 120 per minute per transmitter, it is
35 evident that for signals having a length of 100

1 microseconds, 600,000 non-overlapping signals can be
transmitted each minute. However, because
synchronization symbol 122 is only 20 microseconds long,
3 million non-overlapping synchronization symbol
5 portions of signals 120 can be transmitted each
minute and, because of the ability to data discriminate,
it is estimated that at least about 6 million
transmitters 30, 32, 34 (etc.) can be handled in a
single VLS 20.

10 For purposes of illustrating the present invention,
it may be assumed that transmitters 30, 32, 34 (etc.)
transmit signals 120 once every minute under normal
"vehicle-in-motion" conditions, and that such signals
are transmitted at times t_1 , t_2 , t_3 and so forth,
15 as is diagrammed in Fig. 4. Sequencer 70 is, however,
also configured to provide a short initiating or control
signal 138 at times $t_1 - \Delta t$, $t_2 - \Delta t$, $t_3 - \Delta t$, and
so forth. These control signals 138 are provided, over
respective lines 140 and 142 (Fig. 1), to phase lock
20 loop 88 and to pulse forming network 82, and cause
L-band oscillator 86 to attain the design frequency of
operation (through operation of feed back loop 88) and
cause pulse forming network 82 to be "fired" to provide
(over a line 144) to power amplifier 80 a high power
25 pulse of sufficient duration to enable outputting of
signal 120. Due to this energy efficient configuration
of transmitter 30, 32, 34 (etc.), a single alkaline
battery of the D-cell type should operate the
transmitter for about one year under normal conditions.

30 Sequencer 72 may also be configured, in a manner
known to those skilled in the art, to cause signals 120
to be transmitted at several different, predetermined
repetition rates. As an illustration, provided an
electric signal is input, over a line 146, by motion
35 sensor 100 any time in the one minute interval between

1 routinely-timed transmissions, sequencer 72 will
continue transmitting signals 20 at a normal, exemplary
once per minute rate. However, in the absence of any
motion sensor signals, thereby indicating that the
5 associated vehicle is not moving, sequencer 72 may
automatically select a longer time interval (such as one
hour) between signal transmissions, since less frequent
vehicle location updating is required when the
associated vehicle is not moving. Nevertheless,
10 periodic updating of the vehicle location is still
usually desirable to assure that the transmitter is
properly functioning. This reduced transmission rate by
transmitters mounted on non-moving vehicles reduces
overall transmission traffic, thereby enabling a greater
15 number of vehicles to be included in VLS20 than might
otherwise be possible. Of course, sequencer 72 could
alternatively be configured to inhibit the transmission
of any signal 120 when the vehicle is not in motion.

Sequencer 72 may also be configured so that
20 responsive to electronic signals, over lines 148 and
150, from crash sensor 102 and anti-theft means 104, the
time intervals between transmission of signals 120 is
reduced to less than one minute. Responsive to a crash
indication, signals 120 might, for example, be
25 transmitted every five seconds. Similarly, responsive
to a vehicle tampering indication, the signal
transmissions might be transmitted every ten seconds.
When configured in this manner to provide different,
preestablished transmission periods for different
30 conditions, information as to vehicle status is
effectively "encoded" into signals 120 without actually
changing the format of the signals. Such repetition
rate coding is advantageous if actual encoding of
messages into signals 120 is not permitted by airwave
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1 regulating authorities, such as the F.C.C, or is
otherwise not considered desirable.

Transmitters 30, 32, 34 (etc.), can, with known low-
cost construction techniques be made sufficiently small
5 to be installed in a package 150 (FIG. 5) only about
five inches in diameter and only about one and one half
inches thick. Antenna 84 may correspondingly comprise a
short wire monopole antenna projecting from package
150. A narrow, apertured flange 152 around the base of
10 package 150 enables convenient mounting of the package
to a vehicle (or other object). Because of its small
package size, transmitters 30, 32, 34 (etc.) can
alternatively be mounted on (or concealed in) small
objects such as shipping cartons, luggage and
15 briefcases, and may even be carried by individuals on
their person, if so desired. By the application of
known microelectronic fabrication techniques, the size
of package 150 may be further reduced. Moreover, it is
within the scope of the present invention, for
20 transmitters 30, 32, 34 (etc.) to be integrated into
other electronic equipment, such as automobile AM/FM
radios or CB radios.

Relay stations 24, 26 and 28 relay signals 120 from
vehicle transmitters 30, 32, 34, (etc.) and benchmark
25 transmitters 40, 42 and 44 to processing station 22 for
processing into vehicle location information.
Accordingly, relay stations 24, 26 and 28 preferably
comprise signal repeaters of conventional design, known
in the art. When, however, relay stations 24, 26 and 28
30 are to be mounted onto satellites, the apparatus
selected should be small and light in weight, should
have low power consumption and should be especially
reliable in operation. Because relay stations 24, 26
and 28 are of known, conventional configuration further

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1 description of these stations is neither considered
necessary nor is provided herein.

5 Central processing station 22, as shown in block
diagram form in FIG. 6, comprises generally signal
receiving means 160, signal correlating means 162, a
time-delay-of-arrival (TDOA) processor 164, a data
processor or data processing means 166, operator display
and control means 168 and subscriber interfacing means
170. In turn comprising signal receiving means 160 are
10 respective first, second and third directional antennas
178, 180 and 182, which are aimed towards corresponding
relay stations 24, 26 and 28 (FIG. 1) for separately
receiving relayed signals 120 therefrom. Respectively
associated with antennas 178, 180 and 182 are similar
15 first, second and third RF receivers 184, 186 and 188,
each of which are of conventional design and therefore
require no further description.

Similar, first, second and third signal correlators
190, 192 and 194 comprise signal correlating means 162.
20 Spread spectrum signals 120, received by first receiver
184, via first antenna 178, are serially fed into first
signal correlator 190 over a correlator input line 196.
Similarly, second correlator 192 receives spread
spectrum signals 120 from second receiver 198 over a
25 signal correlator input line 186 and third signal
correlator 194 receives signals 120 from third receiver
188 over line 200. Signal correlators 190, 192 and 194
are configured for sorting out signals 120 which may
overlap one another due to near-simultaneous, random
30 transmissions from different transmitters 30, 32, 34,
(etc.) and 40, 42 and 44 so that corresponding time-
differences-of-arrival can be determined by TDOA
processor 164 and individual transmitter locations can
be determined, in the manner described below.

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1 FIG. 7 illustrates, in functional block diagram
form, one manner in which signal correlators 190, 192
and 194 may advantageously be implemented, first signal
correlator 190 being shown as representative of all
5 three signal correlators. Comprising signal correlator
190, as shown, are a synchronization correlator 210, a
thresholder 212, first and second data correlators 214
and 216 and an Nth data correlator 218 (there being a
total of N data correlators arranged in parallel, only
10 the first, second and Nth data correlators being shown).

 Signals, in spread spectrum format, which are
received by first receiver 184 are fed, over line 196,
to the inputs of synchronization correlator 210 and to
first through Nth data correlators 214-218. Outputs
15 from first through Nth data correlators 214-218 are fed,
over a bus or multiple line 220, to an input of TDOA
processor 164.

 Synchronization correlator 210 comprises, as shown
in Fig. 8, an input register 230 and a store register
20 232; each such register has of a number of cells equal
to the number of chips in signal synchronizing symbol
122 (FIG. 3). As above-described, the number of chips
in synchronizing symbol 122 may be 168. Permanently
stored in store register 232 is the specific pseudo-
25 random synchronizing symbol code used by all signals 120.

 An RF signal 234 (which comprises a string of
single or overlapped transmitter signals 120) received
by receiver 184 from relay station 24 is provided over
line 196 into input register 230. As each chip of
30 signal 234 is fed into register 230, the content of each
cell of the register is compared, in a known manner by
comparing means 236, with the content of each
corresponding cell in store register 232. As each set
of 168 correlating inputs are received by thresholder
35 212, the thresholder outputs a correlation chip on a

1 line 238 to data correlators 214-218. One such
correlation chip is provided by thresholder 212 for each
signal chip fed into input register 230. The string of
correlation chips provided by thresholder 212 make up a
5 thresholder output signal 240.

A maximum value correlation chip will be provided
by thresholder 212 when the contents of all cells of
input register 230 correlate with the contents of all
cells in store register 232. This occurs only when a
10 complete synchronization symbol 122 has been input into
register 230 and thereby indicates that the beginning of
a signal 120 has been received.

When VLS 20 includes a very large number of
transmitters 30, 32, 34 (etc.), signal 234 provided
15 through receiver 184 to input register 230 may
frequently or occasionally comprise two or more
overlapping signals 120 and may, at times, include
overlapping synchronization symbols 122 from different
transmitters. Typically, synchronization correlation
20 will be poorer when overlapping synchronization symbols
122 are present than when only one such symbol is
present. Synchronization symbol discrimination in the
presence of overlapping signals 120 is preferably
provided by conventional "thresholding" techniques. A
25 correlation threshold 242 may thus be established
against which correlation chips provided by thresholder
212 are tested. Threshold 242 is established at a level
such that when the level is exceeded by a correlation
chip output of thresholder 212, a high probability
30 exists that a synchronization symbol has, in fact, been
input into register 230. Similarly, a high probability
exists that if the correlation chips are below threshold
242 a synchronization chip has not been input into input
register 230. As in the case of other thresholding
35 situations, if threshold 242 is set too high,

1 synchronization symbols 122 may fail to be detected and
some signals 120 may be missed; on the other hand, if
threshold 242 is set too low, false indications of
synchronization symbols having been received into input
5 register 230 may be provided. In either event, however,
frequent transmissions of signals 120 by each
transmitter 30, 32, 34 (etc) should still enable
accurate transmitter (vehicle) locations determinations
to be made by processing station 22.

10 Data correlators 214-218 are connected and
configured for receiving signal 234 from receiver 184 in
spread spectrum format and for outputting corresponding,
non-spread spectrum signals 244 over bus 220 to TDOA
processor 166 (FIG. 7). Towards this end, whenever a
15 correlation chip provided by threshold 212 exceeds
threshold 242, the first available one of data
correlators 214-218 is enabled to receive the rest of
signal 120 that has just been identified by
synchronization symbol correlation in synchronization
20 correlator 210. A sufficient number of data correlators
214-218 are provided to accommodate the maximum number
of overlapping signals 120 that are expected to occur in
correlator 190. If, however, no data correlator is
available to accept a signal 120, the signal is
25 automatically discarded. Again, because of the frequent
repetition of signal transmissions from each transmitter
30, 32, 34 (etc.) an occasional discarding of a signal
120 is not considered to significantly affect operation
of VLS 20.

30 The configuration and operation of data correlators
214-218 are substantially the same as described above
for synchronization correlator 210. Continuing with the
assumption that each identification symbol 126 of each
transmitted signal 120 comprises four binary bits,
35 sixteen possible bit patterns (0000, 0001, 0010...1111)

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1 exist for each such symbol. As each chip of each
identification symbol 126 is received into the available
data correlator 214-218, the correlation is checked
5 between the contents of an input register (similar to
input register 130) and the contents of sixteen store
registers (each similar to store register 232) in which
the sixteen different binary arrangements are stored.
When a correlation is found, in the manner above-
described for synchronization symbol correlation, with a
10 particular one of the store registers, the store
register "number" is output over bus 220 to TDOA
processor 164. For such purposes a hexadecimal system
is conveniently used, the hexadecimal representations
being as shown in Table 1, below. In a similar manner,
15 data correlations 214-218 identify and decode message
codes (if any) encoded into the four bits of message
symbol 126, and include such message information in
output signal 244 to TDOA processor 164.

Table 1

20	Decimal	Binary	Hexadecimal
	0	0000	0
	1	0001	1
	2	0010	2
	3	0011	3
25	4	0100	4
	5	0101	5
	6	0110	6
	7	0111	7
	8	1000	8
30	9	1001	9
	10	1010	A
	11	1011	B
	12	1100	C
	13	1101	D
35	14	1110	E
	15	1111	F

1 Accordingly, all 16^6 (16,777,216) possible
transmitter identification numbers permitted by six
symbols 124, each having four bits, can be represented
by six hexadecimal "digits". As an illustrative
5 example, the decimal number 10,705,823 can be
represented hexadecimally as "A35B9F".

 Data correlators 214-218 provide such processed
signals, in non-spread spectrum format, over bus 242 to
TDOA processor 166 (FIG. 7). In addition, data
10 correlators 214-218 encode time of signal arrival
information into signal symbol 126. To enable time
tagging of the signals 120, a clock 246 provides clock
signals (ck) to each of data correlators 214-218.

 In the same manner, second correlator 192 operates
15 on signals 120 received from second relay station 26 by
receiver 186 and provides time-tagged, decoded signals
to TDOA processor 164 over a bus 248 and third correlator
194 operates on signals 120 received from relay station
26 by receiver 188 and provides time-tagged signals to
20 the TDOA processor over a bus 250 (FIG. 6).

 TDOA processor 164 sorts the time-tagged signals
from first, second and third correlators 190, 192 and
194 according to transmitter identification number and
time of arrival. When a set of three time-tagged
25 signals which represent the same signal 120 separately
relayed by stations 24, 26 and 28, and thus arriving at
three different times in correlators 190, 192 and 194,
are found and the times of arrival are within a specific
time range assuring that the signals all originated at
30 the same time and are not from different transmissions,
pairs of time differences of arrival are computed by
considering different pairs of signals in each set.
This time difference of arrival data is provided by TDOA
processor 164 to data processor 166 over a bus 252.

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1 From the time-difference-of-arrival data provided
by TDOA processor 164, data processing means 166, which
may comprise a general purpose computer, computes the
location of the corresponding transmitter 30, 32, 34
5 (etc.) in accordance with known techniques. These known
techniques compute the intersections of two hyperbolic
surfaces of revolution with the transmitter location
being on the line of intersection of such surfaces; in
the described embodiment having three relay stations 24,
10 26 and 28, separate altitude information is required to
establish a point on the intersection line. For surface
vehicles, such altitude is assumed, for example, to be
zero feet. To establish the three dimensional
coordinates for non-surface vehicles (e.g. aircraft) a
15 fourth relay station, similar to stations 24-28, may be
provided. In such case, three hyperbolic surfaces of
revolution are derived and a common, intersection point
(x,y,z) is determined as the transmitter coordinates.
Such a technique of location determination is, for
20 example, described in the above-referenced patent number
4, 215, 345 to MacDoran.

After the transmitter location information has been
obtained in the above-described manner, the transmitter
identification is cross-checked with stored
25 transmitter-vehicle identification and vehicle location
information is provided, through a bus 254 and interface
means 170, to appropriate system subscriber stations 60
and 62. Alternatively, or in addition, all or some of
the computed vehicle location information may be
30 provided, over a bus 256, to operator display means 168
(FIG. 6).

Data processing means 166 further enable the
counting of the repetition rate at which signals are
transmitted by individual ones of transmitters 30, 32,
35 34 (etc.), "decoding" of signal repetition rate messages

1 (such as "vehicle-not-in-motion," "vehicle crash" and
"vehicle intrusion/theft") and providing this
information to system subscribers 60 and 62. Likewise,
5 data processing means 166 decode messages (if any)
encoded into signal symbols 126 and provides such
information to subscribers 60 and 62.

As mentioned above, computed location information
relating to benchmark transmitters 40, 42 and 44
importantly provides calibration information for VLS
10 20. In this regard, the locations of benchmark
transmitters 40, 42 and 44 are determined in the manner
described for obtaining the locations of vehicle
transmitters 30, 32, 34 (etc.). The computed benchmark
locations are correlated, by data processing means 166,
15 with benchmark transmitter surveyed location information
stored in the data processing means. As long as the
computed and surveyed locations of all the benchmark
transmitters correlate within allowable error limits, it
can reasonably be assumed that: (i) benchmark
20 transmitters 40, 42 and 44 have not been moved, (ii)
relay stations 24, 26 and 28, whose locations are used
in computing transmitter locations, have not moved
relative to the geographical region covered, and (iii)
data processing portions of VLS 20 are properly
25 functioning.

If, however, none of the benchmark computed and
surveyed locations correlate within allowable limits of
error, and if relay stations 24, 26 and 28 are satellite
mounted, the possibility exists that one or more of the
30 relay stations has moved due to satellite movement
relative to central processing station 22. If it is
determined that benchmark transmitters 40, 42 and 44
have, in fact, not been moved and if the computational
processes of VLS 20 are determined to be properly
35 functioning, the differences between the computed and

1 surveyed locations of benchmark transmitters 24, 26 and
28 can then be used for recalibrating the locations of
relay stations 24, 26 and 28. These recalibrated
positions of relay stations 24, 26 and 28 can
5 subsequently be used in future computations of vehicle
transmitter locations.

The use of three relay stations 24, 26 and 28 has
hereinabove been described, three such relay stations
being sufficient to provide two dimensional,
10 ground-level location information, as is usually
satisfactory for ground vehicles. However, for vehicles
in mountainous regions and for aircraft, three
dimensional location information is, or may be,
required. VLS 20 can then be expanded, and it is within
15 the scope of the invention to so expand the VLS, to
incorporate a fourth relay station similar to relay
stations 24, 26 and 28 and to include corresponding
receiving antenna, similar to antennas 178, 180 and 182;
a corresponding receiver, similar to receivers 184, 186
20 and 188 and a corresponding, fourth correlator similar
to correlators 190, 192 and 194 and to expand the TDOA
and data processing capabilities to handle additional
computations necessary for determining a third location
coordinate.

25 It is further to be understood that for purposes of
description, correlation means 162, TDOA processor 164
and data processing means 166 have been illustrated in
the Figures and have been described as being separate.
In practice, however, all such portions of processing
30 station 22 may be combined and may comprise a general
purpose computer.

The present inventors have estimated that the
individual cost of transmitters 30, 32, 34, (etc.) and
40, 42 and 44, in production quantities, will be less
35 than 100 dollars, that the cost of central processing

1 station 22 will be about three million dollars,
(exclusive of property and buildings) and that the
per-year cost of relay stations 24, 26 and 28 will be
about sixteen million dollars. From these cost
5 estimates, it is evident that the per-transmitter cost
(that is, per-vehicle cost) is very small provided a
sufficiently large number of vehicles are covered by VLS
20. It is this unique ability of the present VLS 20 to
handle very large numbers of transmitters that
10 importantly permits the system to be economically
attractive to subscribers.

Although there has been described herein a vehicle
locating system in accordance with the present invention
for purposes of illustrating the manner in which the
15 invention may be used to advantage, it will be
appreciated that the invention is not limited thereto.
Accordingly, any and all modifications or variations
which may occur to those skilled in the art are to be
considered to be within the scope and spirit of the
20 invention as defined in the appended claims.

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THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. A vehicle locating system for remotely determining the locations of a comparatively large number of vehicles operating within a specific geographical region, the vehicle locating system comprising:

- a. a number of similar, automated radio frequency transmitters adapted for mounting on vehicles, each of said transmitters being configured for transmitting radio frequency signals that are similar except that each transmitter has means for encoding onto the signal transmitted thereby a unique transmitter identification code, each of the transmitters having means for causing the transmitted signals to be repeated at predetermined intervals, each of the transmitters operating independently of one another and hence in a random manner relative to one another;

each said transmitter including means for encoding a synchronization code into each transmitted signal, the synchronization code being the same for each said transmitter;

- b. first, second and third elevated radio signal relay stations for receiving the radio frequency signals from said transmitters and for relaying said received signals, the relay stations being spaced apart from one another in known locations relative to said geographical region covered by the vehicle locating system;

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- c. a central processing station having means for separately receiving the relayed radio frequency signals from each of the relay stations, means for encoding onto the received signals the time of arrival at said processing station and means for determining from time differences of arrival (TDOA) of the signals from the relay stations a location of each transmitter that is transmitting signals;
- the central processing means for separating the relayed signals from one another including means for correlating the signal synchronization code with a corresponding stored signal synchronization code in a manner enabling individual signals to be identified even in the presence of overlapping signals.

2. The vehicle locating system as claimed in Claim 1 wherein the synchronization code is encoded into a synchronization symbol portion of the signal, the synchronization symbol being no more than about twenty microseconds in length.

3. The vehicle locating system as claimed in Claim 1 wherein the synchronization symbol is at the beginning of each signal so as to enable identification of the beginning of each signal received by the central processing station.

4. The vehicle locating system as claimed in Claim 1 wherein each of the transmitters includes means for coding the signals transmitted thereby in spread spectrum format so as to enhance the ability of the central processing station to separate the signals from one another.




5. The vehicle locating system as claimed in Claim 1 wherein at least some of the transmitters include means for enabling the signal repetition rate to be varied so as to enable the communication of messages from the transmitter to the central processing station by changing the signal repetition rate.

6. The vehicle locating system as claimed in Claim 5 including motion sensing means associated with said at least some of the transmitters and wherein the means for enabling the signal repetition rate to be varied causes the transmitter to transmit signals at a first repetition rate when the motion sensing means senses that the transmitter is at rest and at a second repetition rate when the motion sensing means senses that the transmitter is in motion.

7. The vehicle locating system as claimed in Claim 6 wherein the first signal repetition rate is substantially less than the second signal transmission rate so that fewer signals are transmitted by those transmitters that are at rest than by those transmitters that are in motion, signal traffic being thereby reduced over that which would otherwise occur if all transmitters transmitted signals at the second rate.

8. The vehicle locating system as claimed in Claim 5 including vehicle anti-theft means adapted for installation on vehicles to which said at least some of the transmitters are mounted, said anti-theft means providing an electric signal in response to tampering of the vehicle in which the anti-theft means are installed, and wherein said means for enabling the repetition rate of the signal to be varied is responsive to the electric signal from the anti-theft means for causing the signal repetition rate to be increased from the



normal transmitting rate to a preselected transmission rate associated with a vehicle tampering situation.

9. The vehicle locating system as claimed in Claim 5 including vehicle crash sensing means adapted for installing on vehicles to which said at least some of the transmitters are mounted and wherein the means for enabling the signal repetition rate to be varied is responsive to the vehicle crash sensing means for causing the signal transmission rate to be increased from the normal transmitting rate to a preselected transmitting rate associated with a vehicle crash situation.

10. The vehicle locating system as claimed in Claim 1 including at least one benchmark transmitter adapted for being mounted at a known, fixed location relative to said geographical region.

11. The vehicle locating system as claimed in Claim 10 wherein the benchmark transmitter is configured to transmit radio frequency signals similar to those transmitted by the transmitters that are adapted for vehicle mounting.

12. The vehicle locating system as claimed in Claim 10 wherein the central processing station includes means for determining the location of the relay stations from the time differences of arrival (TDOA) information relating to the signals transmitted by the benchmark transmitter, system calibration being thereby enabled.

13. The vehicle locating system as claimed in Claim 1 including means associated with at least some of the transmitters for storing preselected message codes and means for enabling said message codes to be

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selectively encoded into signals transmitted by said at least some of the transmitters.

14. The vehicle locating system as claimed in Claim 1 wherein each of the transmitted signals is formatted having a synchronization symbol at the beginning of each signal, followed by a plurality of transmitter identification symbols.

15. A vehicle locating system for remotely determining the locations of a comparatively large number of vehicles operating within a specific geographical region, the vehicle locating system comprising:

- a. a number of similar, automated radio frequency transmitters adapted for mounting on vehicles, each of said transmitters being configured for transmitting radio frequency signals that are similar except that each transmitter has means for encoding onto the signal transmitted thereby a unique transmitter identification code, each of the transmitters having means for causing the transmitted signals to be repeated at predetermined intervals, each of the transmitters operating independently of one another and hence in a random manner relative to one another;

each of the transmitted signals being formatted having a synchronization symbol at the beginning of each signal, followed by a plurality of transmitter identification symbols;

- b. first, second and third elevated radio signal relay stations for receiving the radio frequency signals from said transmitters and

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for relaying said received signals, the relay stations being spaced apart from one another in known locations relative to said geographical region covered by the vehicle locating system;

- c. a central processing station having means for separately receiving the relayed radio frequency signals from each of the relay stations, means for encoding onto the received signals the time of arrival at said processing station and means for determining from time differences of arrival (TDOA) of the signals from the relay stations a location of each transmitter that is transmitting signals;

the central processing means for separating the relayed signals from one another including synchronization correlation means for detecting the synchronization symbol at the beginning of each received signal and data correlating means for determining from the identification symbols following the synchronization symbol the transmitter identification associated with each received signal.

16. The vehicle locating system as claimed in Claim 15 wherein each identification symbol comprises a plurality of data bits and wherein the means for determining the transmitter identification code correlates each of the data bits of each of the identification symbols with stored possible codes to enable each identification symbol to be decoded.

17. The vehicle locating system as claimed in Claim 15 wherein each signal comprises six identification symbols, each said identification symbol

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comprising four bits, a total of 16^6 different transmitter identifications being thereby enabled.

18. A vehicle locating system for remotely determining the locations of a comparatively large number of vehicles operating within a specific geographical region, the vehicle locating system comprising:

- a. a number of similar, automated radio frequency transmitters adapted for mounting on vehicles, each of the transmitters including means for formatting signals to be transmitted by the transmitters, said signal formatting means formatting the signals with a synchronization symbol followed by a plurality of transmitter identification symbols, the synchronization symbol containing the same data for all the transmitters and the transmitter identification symbols containing data uniquely identifying the associated transmitter, each of the transmitters further including means for causing the signals transmitted by the transmitters to be repeated at a predetermined repetition rate, each of the transmitters operating independently of one another and hence in a mutually random manner;
- b. first, second and third elevated radio signal relay stations for receiving the signals transmitted by the transmitters and for relaying said received signals, the relay stations being spaced apart from one another in known locations relative to the geographical region covered by the vehicle locating system; and

- c. a central processing station having means for separately receiving the relayed radio frequency signals from each of the relay stations, means for separating the relayed signals from one another, means for encoding onto the received signals the time of arrival at the processing station and means for determining from time differences of arrival of the signals at the processing station a location of each transmitter that is transmitting signals, said means for separating the relayed signals from one another including synchronization correlation means for determining from the synchronization symbol the beginning of individual ones of the relayed signals and data correlating means for determining from the identification symbols the transmitter identification code associated with each received signal.

19. The vehicle locating system as claimed in Claim 18 wherein each identification symbol comprises a plurality of data bits and wherein each identification symbol comprises a plurality of data bits and wherein the data correlating means correlates each of the identification symbols with stored possible codes to enable each identification symbol to be decoded.

20. The vehicle locating system as claimed in Claim 17 wherein each signal comprises six identification symbols and each identification symbol comprises four data bits enabling sixteen codes per identification symbol, a total of 16^6 different transmitter identifications being thereby made possible

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21. The vehicle locating system as claimed in Claim 18 wherein the synchronization symbol is no longer than twenty microseconds.

22. The vehicle locating system as claimed in Claim 18 wherein the length of each signal is no more than about one hundred microseconds.

23. A vehicle locating system for remotely determining the locations of a comparatively large number of vehicles operating within a specific geographical region, the vehicle locating system comprising:

- a. a number of similar, automated radio frequency transmitters adapted for mounting on vehicles, each of said transmitters being configured for transmitting radio frequency signals that are similar for all said transmitters except that each transmitter has means for encoding onto the signal transmitted thereby a unique transmitter identification code, and each of said transmitters having means for encoding a synchronization code into each transmitted signal, the synchronization code being the same for each said transmitter, each of the transmitters further including means for causing the signals to be repeated at a predetermined repetition rate, each of the transmitters operating independently of one another and hence in a mutually random manner, at least some of the transmitters having means enabling the signal repetition rate to be varied so as to enable messages to be sent by the at least some of the transmitters by varying the signal repetition rate;

- b. first, second and third elevated radio signal relay stations for receiving the radio frequency signals from said transmitters and for relaying said received signals, the relay stations being spaced apart from one another in known locations relative to said geographical region covered by the vehicle locating system; and
- c. a central processing station having means for separately receiving the relayed radio frequency signals from each of the relay stations, means for separating the relayed signals from one another, means for encoding into the received signals the time of arrival at said processing station, means for determining from differences in time arrival of the signals from the relay stations a location of each transmitter that is transmitting signals, and means for correlating the signal synchronization code with a corresponding stored signal synchronization code in a manner enabling individual signals to be identified even in the presence of overlapping signals.

24. A vehicle locating system for remotely determining the locations of a comparatively large number of vehicles operating within a specific geographical region, the vehicle locating system comprising:

- a. a number of similar, automated radio frequency transmitters adapted for mounting on vehicles, each of said transmitters being configured for transmitting radio frequency signals that are similar for all said transmitters except that each transmitter has

means for encoding onto the signal transmitted thereby a unique transmitter identification code, each of the transmitters further including means for causing the signals to be repeated at a predetermined repetition rate, each of the transmitters operating independently of one another and hence in a mutually random manner, at least some of the transmitters having means enabling the signal repetition rate to be varied so as to enable messages to be sent by the at least some of the transmitters by varying the signal repetition rate;

- b. first, second and third elevated radio signal relay stations for receiving the radio frequency signals from said transmitters and for relaying said received signals, the relay stations being spaced apart from one another in known locations relative to said geographical region covered by the vehicle locating system;
- c. a central processing station having means for separately receiving the relayed radio frequency signals from each of the relay stations, means for separating the relayed signals from one another, means for encoding into the receive signals the time of arrival at said processing station and means for determining from differences in time arrival of the signals from the relay stations a location of each transmitter that is transmitting signals; and
- d. motion sensing means associated with said at least some of the transmitters and wherein the means for enabling the signal repetition rate to be varied causes the transmitter to

transmit signals at a first repetition rate when the motion sensing means senses that the transmitter is at rest and at a second repetition rate when the motion sensing means senses that the transmitter is in motion, the first signal repetition rate being substantially less than the second signal transmission rate so that fewer signals are transmitted by those transmitter that are at rest than by those transmitters that are in motion, signal traffic being thereby reduced over that which would otherwise occur if all transmitters transmitted signals at the second rate.

25. A vehicle locating system for remotely determining the locations of a comparatively large number of vehicles operating within a specific geographical region, the vehicle locating system comprising:

- a. a number of similar, automated radio frequency transmitters adapted for mounting on vehicles, each of said transmitters being configured for transmitting radio frequency signals that are similar for all said transmitters except that each transmitter has means for encoding onto the signal transmitted thereby a unique transmitter identification code, each of the transmitters further including means for causing the signals to be repeated at a predetermined repetition rate, each of the transmitters operating independently of one another and hence in a mutually random manner, at least some of the transmitters having means enabling the signal repetition rate to be varied so as to enable messages to be sent by

- the at least some of the transmitters by varying the signal repetition rate;
- b. first, second and third elevated radio signal relay stations for receiving the radio frequency signals from said transmitters and for relaying said received signals, the relay stations being spaced apart from one another in known locations relative to said geographical region covered by the vehicle locating system;
 - c. a central processing station having means for separately receiving the relayed radio frequency signals from each of the relay stations, means for separating the relayed signals from one another, means for encoding into the receive signals the time of arrival at said processing station and means for determining from differences in time arrival of the signals from the relay stations a location of each transmitter that is transmitting signals; and
 - d. vehicle anti-theft means adapted for installation on vehicles to which said at least some of the transmitters are mounted, said anti-theft means providing an electric signal in response to tampering of the vehicle in which the anti-theft means are installed, and wherein said means for enabling the repetition rate of the signal to be varied is responsive to the electric signal from the anti-theft means indicating a vehicle tampering condition for causing the signal repetition rate to be increased from the normal transmitting rate to a preselected transmission rate associated with a vehicle tampering situation.

26. A vehicle locating system for remotely determining the locations of a comparatively large number of vehicles operating within a specific geographical region, the vehicle locating system comprising:

- a. a number of similar, automated radio frequency transmitters adapted for mounting on vehicles, each of said transmitters being configured for transmitting radio frequency signals that are similar for all said transmitters except that each transmitter has means for encoding onto the signal transmitted thereby a unique transmitter identification code, each of the transmitters further including means for causing the signals to be repeated at a predetermined repetition rate, each of the transmitters operating independently of one another and hence in a mutually random manner, at least some of the transmitters having means enabling the signal repetition rate to be varied so as to enable messages to be sent by the at least some of the transmitters by varying the signal repetition rate;
- b. first, second and third elevated radio signal relay stations for receiving the radio frequency signals from said transmitters and for relaying said received signals, the relay stations being spaced apart from one another in known locations relative to said geographical region covered by the vehicle locating system;
- c. a central processing station having means for separately receiving the relayed radio frequency signals from each of the relay stations, means for separating the relayed signals from one another, means for encoding

into the receive signals the time of arrival at said processing station and means for determining from differences in time arrival of the signals from the relay stations a location of each transmitter that is transmitting signals; and

- d. vehicle crash sensing means adapted for installing on vehicles to which said at least some of the transmitters are mounted and wherein the means for enabling the signal repetition rate to be varied is responsive to the vehicle crash sensing means indicating a vehicle crash condition for causing the signal transmission rate to be increased from the normal transmitting rate to a preselected transmitting rate associated with a vehicle crash situation.

27. A vehicle locating system for remotely determining the locations of a comparatively large number of vehicles operating within a specific geographical region, the vehicle locating system comprising:

- a. a number of similar, automated radio frequency transmitters adapted for mounting on vehicles, each of said transmitters being configured for transmitting radio frequency signals that are similar for all said transmitters except that each transmitter has means for encoding onto the signal transmitted thereby a unique transmitter identification code, each of the transmitters further including means for causing the signals to be repeated at a predetermined repetition rate, each of the transmitters operating independently on one another and hence in a mutually random manner,

- at least some of the transmitters having means enabling the signal repetition rate to be varied so as to enable messages to be sent by the at least some of the transmitters by varying the signal repetition rate;
- b. first, second and third elevated radio signal relay stations for receiving the radio frequency signals from said transmitters and for relaying said received signals, the relay stations being spaced apart from one another in known locations relative to said geographical region covered by the vehicle locating system;
 - c. a central processing station having means for separately receiving the relayed radio frequency signals from each of the relay stations, means for separating the relayed signals from one another, means for encoding into the received signals the time of arrival at said processing station and means for determining from differences in time arrival of the signals from the relay stations a location of each transmitter that is transmitting signals; and
 - d. means associated with at least some of the transmitters for storing preselected message codes and means for enabling said message codes to be selectively encoded into signals transmitted by said at least some of the transmitters.

28. The vehicle locating system as claimed in Claim 23 wherein each of the transmitted signals is formatted having a synchronization symbol at the beginning of each signal followed by a plurality of transmitter identification symbols, wherein the central

processing station means for separating the relayed signals from one another include synchronization correlation means for determining from the synchronization symbols the beginning of each received signal and data correlating means for determining from the identification symbols the transmitter identification code associated with each received signal, wherein each identification symbol comprises a plurality of data bits and wherein the means for determining the transmitter code correlates each of the data bits of each of the identification symbols with stored possible codes to enable each identification symbol to be decoded.

29. The vehicle locating system as claimed in Claim 27 wherein each signal comprises six identification symbols, each said identification symbol comprising four bits, a total of 16^6 different transmitter identifications being thereby enabled.

30. The vehicle locating system as claimed in Claim 23 including at least one benchmark transmitter adapted for being mounted at a known, fixed location relative to said geographical region, the benchmark transmitter being configured to transmit radio frequency signals similar to those transmitted by the transmitters that are adapted for vehicle mounting and wherein the central processing station includes means for determining the location of the relay stations from the time of arrival difference information relating to the signals transmitted by the benchmark transmitter, system calibration being thereby enabled.

31. The vehicle locating system as claimed in Claim 23 wherein each of the transmitters includes means for coding the signals transmitted thereby in spread spectrum format so as to enhance the ability of the central processing station to separate the signals from one another.



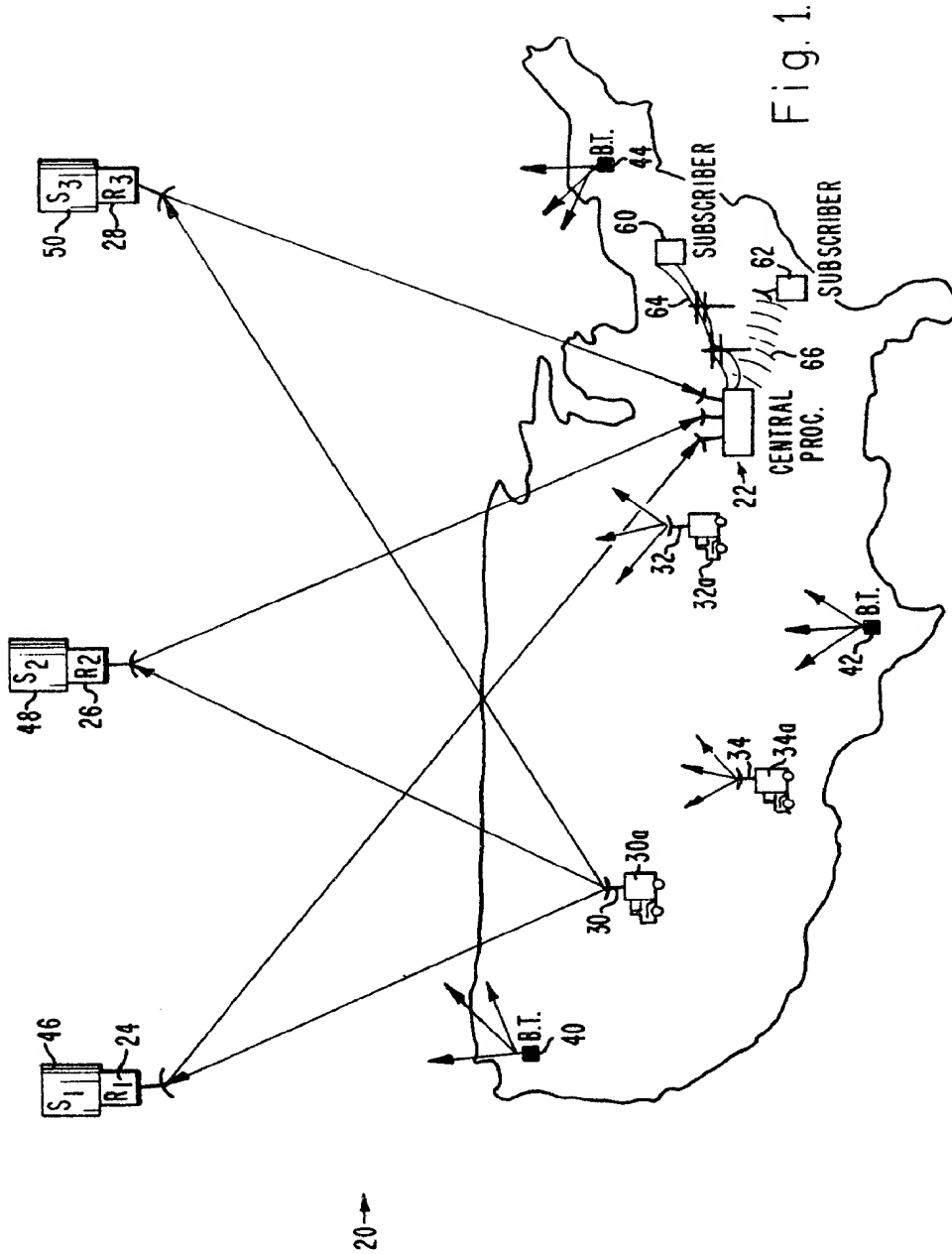
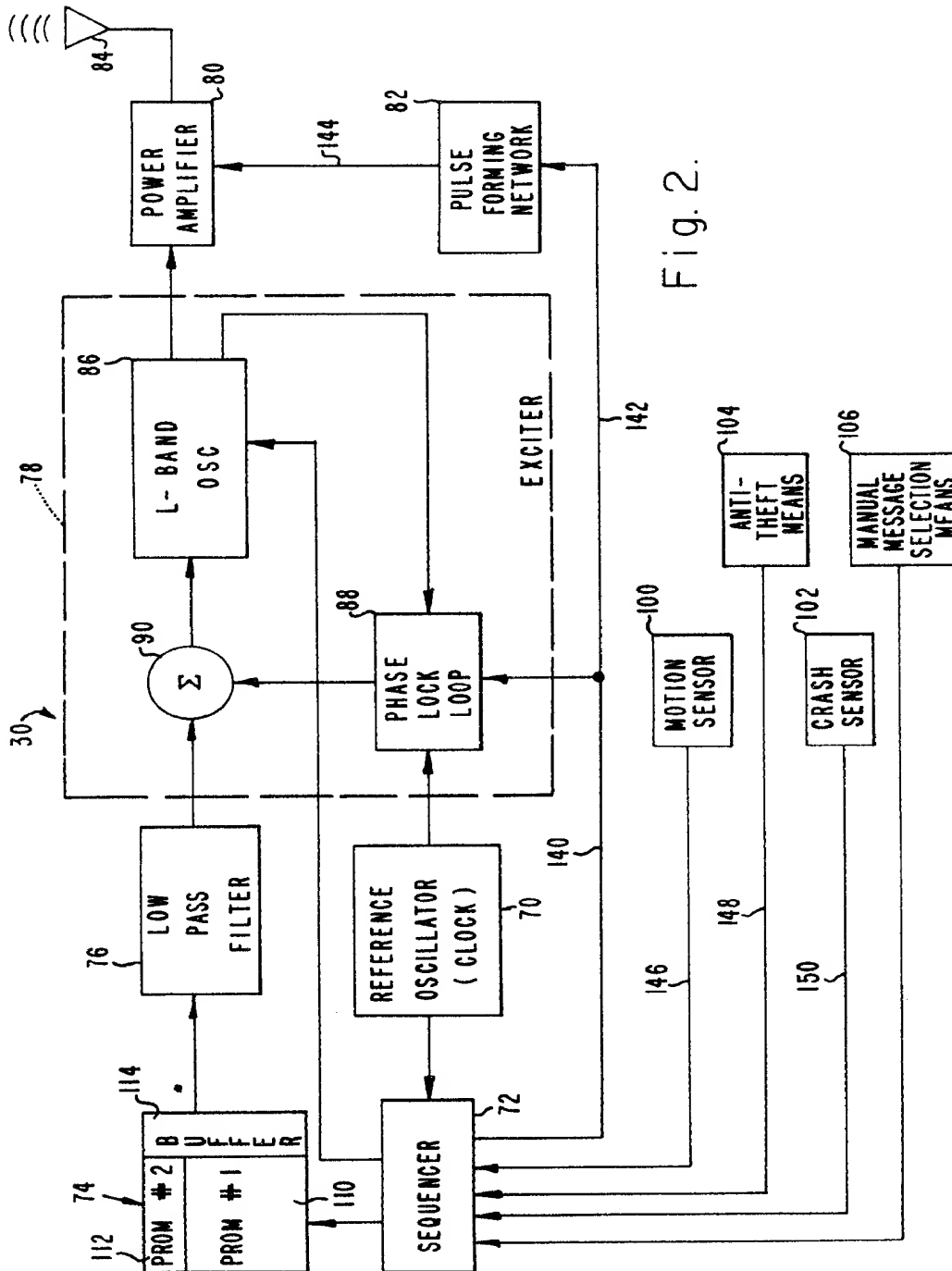


Fig. 1.



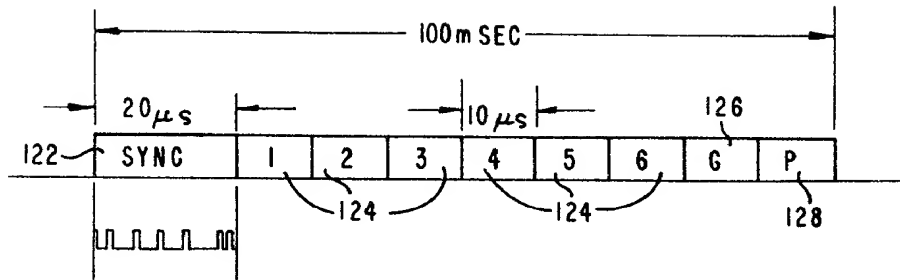


Fig. 3.

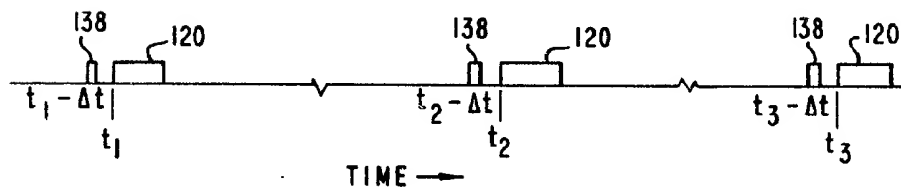


Fig. 4.

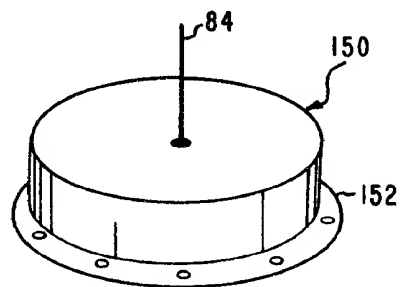


Fig. 5.

Sign of the...

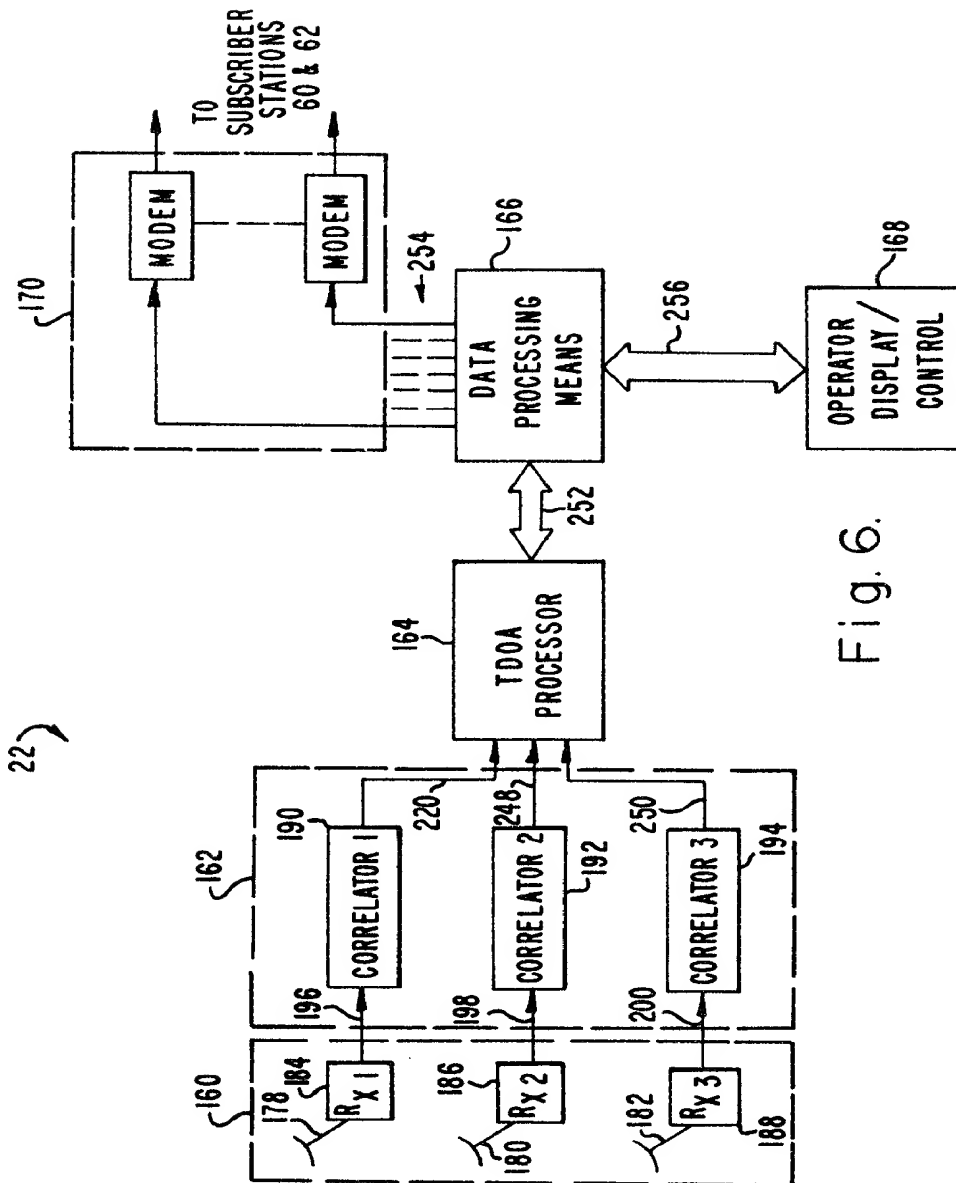


Fig. 6.

See Fig. 1 for details

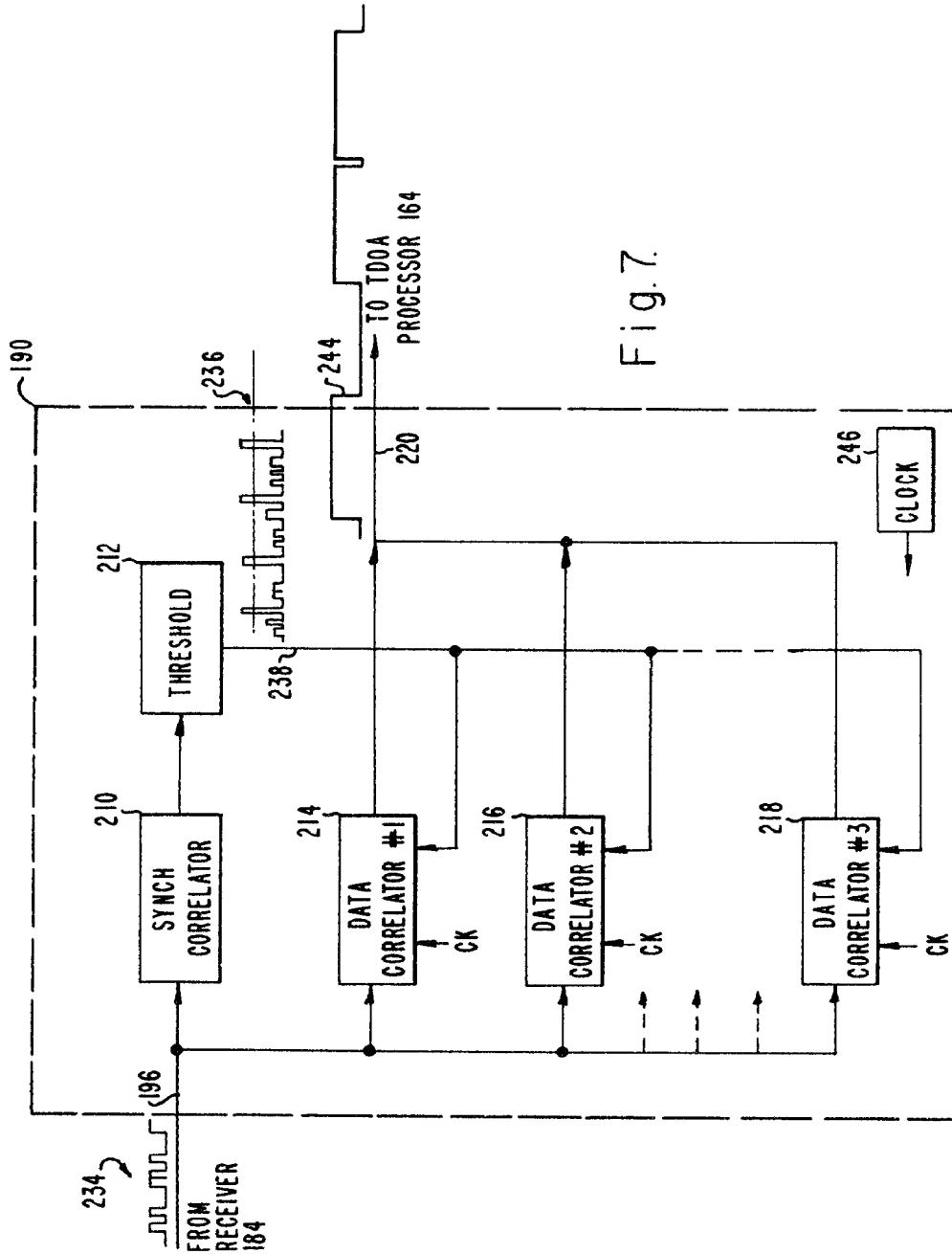


Fig. 7.

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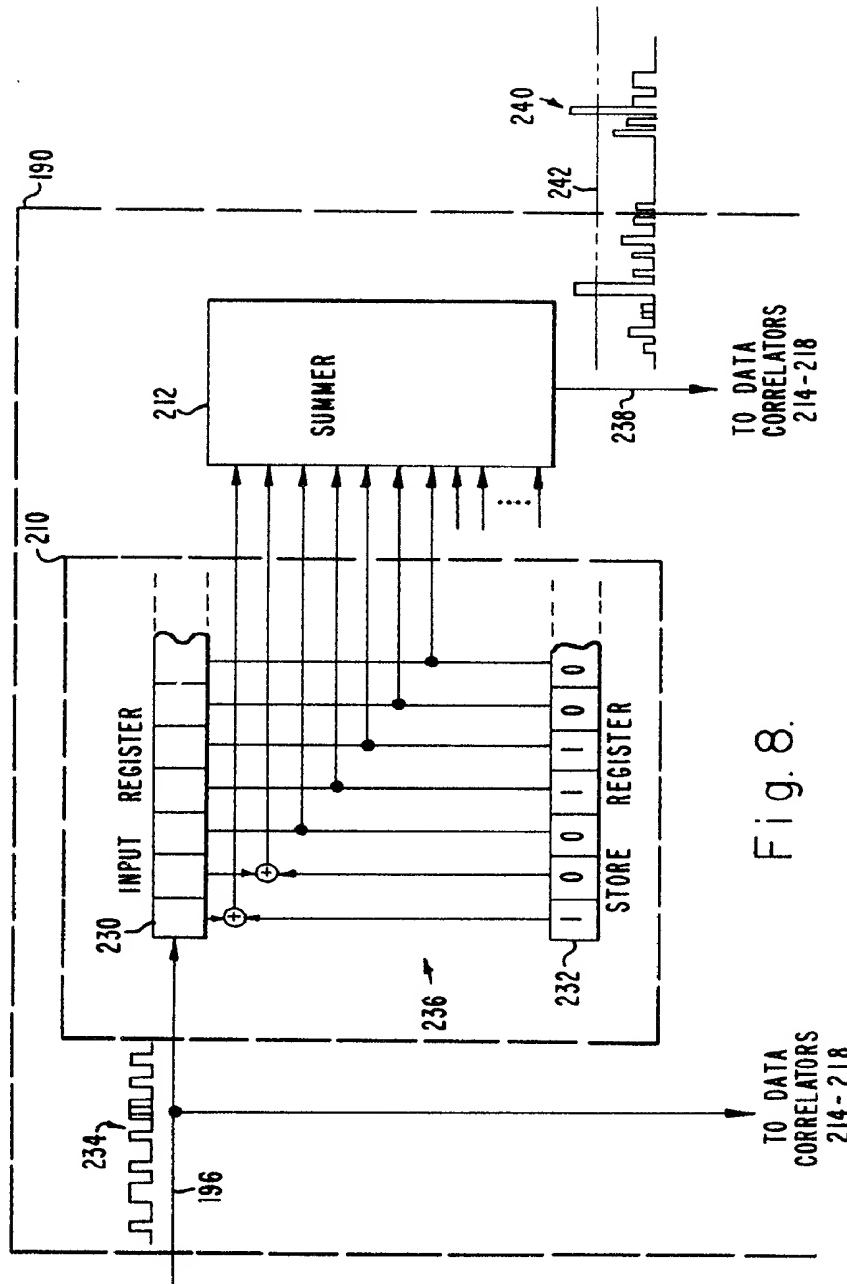


Fig. 8.

Sum of products

